TROPOSPHERIC LAPSE RATES OVER SELECTED OCEAN REGIONS WITH APPLICATION TO THE CONSTRUCTION OF 700 AND 500 MILLIBAR CHARTS

BY

DAVID McDONALD DIBRELL

THESIS
D52

TROPOSPHERIC LAPSE RATES OVER SELECTED OCEAN REGIONS WITH APPLICATION TO THE CONSTRUCTION OF 700 AND 500 MILLIBAR CHARTS

by
D. M. Dibrell

TROPOSPHERIC LAPSE RATES OVER SELECTED OCEAN REGIONS WITH APPLICATION TO THE CONSTRUCTION OF 700 AND 500 MILLIBAR CHARTS

by
David McDonald Dibrell,
Lieutenant, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
IN AEROLOGY

United States Naval Postgraduate School
Monterey, California
1950

This work is accepted as fulfilling
the thesis requirements for the degree of

MASTER OF SCIENCE
IN AEROLOGY

from the
United States Naval Postgraduate School

PREFACE

The purpose of this study was to investigate the daily values of the mean-effective lapse rate over certain ocean regions and thereby to provide a table of probable values of this quantity for the extrapolation of upper pressure surface heights from observed surface data. Season, latitude, wind direction and surface pressure were employed as parameters for separation of cases.

This work was conducted at the United States Naval Postgraduate School, Monterey, California, during the period December 1949 to May 1950. The investigation was prompted by the construction and distribution of multi-variate diagrams for the computation of upper pressure surface heights from sea level temperature, pressure, and mean effective lapse rate. These diagrams, designed by Professor G. J. Haltiner of the Department of Aerological Engineering of the United States Naval Postgraduate School, require an estimation of the mean effective lapse rate between sea level and the desired pressure surface. The investigation attempts to provide an objective selection of the appropriate lapse rate under varying conditions. The assistance and encouragement of Professor Haltiner in the preparation of this thesis is gratefully acknowledged.

TABLE OF CONTENTS

Page

CERTIFICATE OF APPROVAL i

PREFACE ii

TABLE OF CONTENTS iii

LIST OF ILLUSTRATIONS iv

CHAPTER

I. INTRODUCTION 1

II. METHOD OF ANALYSIS 4

III. DISCUSSION OF RESULTS AND SUGGESTIONS FOR FURTHER INVESTIGATION 7

BIBLIOGRAPHY 14

APPENDICES

I. Frequency Tables of Observations in Groups Defined by Latitude and 500 mb Mean Effective Lapse Rate 15

II. Frequency Table of Observations in Groups Defined by Surface Wind Direction and 500 mb Mean Effective Lapse Rate, After Segregation into Ten Degree Latitude Bands 16

III. Frequency Tables of Observations in Groups Defined by Surface Pressure and 500 mb Mean-Effective Lapse Rate, After Segregation into Ten Degree Latitude Bands 20

IV. Frequency Tables of Observations in Groups Defined by Successive Separation According to Season, Latitude, Wind Direction, and Pressure 24

LIST OF ILLUSTRATIONS

Page

TABLE 1. Suggested Mean Effective Lapse Rate Values 8

TABLE 2. Monthly Mean Data for Selected Weather Stations 9

TABLE 3. Test Data Results 10

I. INTRODUCTION

The desirability of increasing the accuracy of upper pressure surface analysis in regions of sparse radiosonde coverage is recognized by all meteorologists. Several methods have been suggested for improving the analysis of these charts, among which are the extrapolation of heights from sea level data, the assumption of continuity and predictable development of the thickness pattern between layers, the construction of temperature anomaly patterns, and others. All of these have proved value and several are widely employed.

The purpose of this paper is to make an objective investigation of radiosonde reports from ocean stations and to set forth suggested values of mean effective lapse rates for various locations and surface weather conditions. These selected values will then be employed to extrapolate the heights of the desired pressure surfaces from observed sea level values of temperature and pressure. This latter step is to be accomplished by the use of multi-variate diagrams which yield the height of the pressure surface using an estimated mean effective lapse rate value and the sea level temperature and pressure for integration of the hydrostatic equation.

A brief review of current methods of obtaining suitably accurate analysis of upper pressure surface charts in regions of poor radiosonde coverage is presented. The universally accepted approximation of assuming a moist adiabatic lapse rate when synoptic observations indicate that such a lapse rate exists is presented in many standard texts. Unfortunately,

in all but the most recent works, this method is presented for the extrapolation of surface data into pressures for a given upper level chart. An example of this presentation is included in the Handbook of Meteorology [1] . Haltiner and Eaton [2] have published, in tabular form, the results of this method for use in constant pressure analysis.

The method of the Extended Forecast Section of the U. S. Weather Bureau, as reported by Namias [4, 5] , is based on the so-called "differential" technique, but with certain important improvements. The thickness pattern of the various atmospheric layers is employed but the estimate of thickness is improved "by judicious distortion of the thickness isograms, or, in effect, by drawing anomalies of thickness." The fact that this method has been retained and is an integral part of the operation of the Extended Forecast Section is an effective demonstration of its worth. However, the data, computing devices, and staff required for efficient use of this method are seldom available to other weather forecast units.

Most recently, Haltiner [3] , has prepared and issued diagrams for the extrapolation of the heights of upper constant pressure surfaces from sea level temperature and pressure with the assignment of a value to the mean effective lapse rate between sea level and the 700 or 500 millibar pressure surface. Because of the lack of statistical studies of oceanic lapse rates in the literature, the selection of an appropriate lapse rate is primarily subjective with only comparatively broad limitations imposed

by theoretical considerations. It is believed that the results of the present investigation will introduce a modicum of objectivity into the selection of mean effective lapse rate values and will materially reduce the opportunity for large errors.

The data used in this investigation were obtained from a one year file of the Daily Upper Air Bulletin [7] , namely, from October 1948 through September 1949. The reader is reminded that these data are unedited. Certain obvious errors have been corrected but it is considered likely that some of the "fringe" values obtained in this study are the result of erroneous data.

Two distinct methods of presenting the results of the work are utilized. In the first, the 500 millibar mean effective lapse rate is separated successively according to (1) season; (2) latitude; (3) wind direction, and (4) sea level pressure. In the second, the monthly mean data, with accompanying statistical parameters, is presented for each of the several reporting ocean weather stations.

A test of the effectiveness of the suggested values of the mean effective lapse rate is made and the results reported as mean error from the observed heights. The test is considered indicative only, since, because of non-availability of other data, a random sample of reports from the primary data was used.

II. METHOD OF ANALYSIS

From the Upper Air Bulletin the following data were recorded on columnar paper, each radiosonde report with associated sea level data filling one line: a) station number or letter; b) date; c) latitude and longitude; d) sea level wind direction and force; e) sea level pressure; f) sea level temperature; g) height of the 700 mb surface; h) temperature at the 700 mb surface; i) height of the 500 mb surface; and k) temperature at the 500 mb surface.

With the exception of the autumn data, which was from 1948, only those radiosonde reports were used where all of the above information was available. Where complete data for the 0300 GCT sounding was not reported, the 1500 GCT sounding was used. A total of 1398 reports were recorded and analyzed.

The mean lapse rate from sea level to each of the upper surfaces was computed and entered in columns reserved therefore. Using the multivariate diagrams and entering with the observed height, the sea level temperature and pressure, a mean effective lapse rate from sea level to each of the upper surfaces was determined and entered.

All entries were then transferred to 3 x 5 cards to facilitate the various separations. On each card was entered the following information: latitude, longitude, date (1500 GCT soundings in lieu of 0300 GCT soundings were indicated by a bar over the date), station number or letter, sea level pressure, sea level wind direction and force, sea level temperature, mean lapse rate and mean effective lapse rate from sea level

to each of the upper surfaces. On the reverse of the card a serial number of the sounding was entered which corresponded to a similar number against the sounding on the original columnar sheets.

The mean effective lapse rate from sea level to 700 mb was correlated for a sample period (one month) with the mean effective lapse rate from sea level to 500 mb. The result of this correlation indicated the practicability of using the "500 mb mean effective lapse rate" exclusively for further analysis.

The following notes should be made. All data used for each sounding in this investigation were for the same time. This differs from the normal practice of extrapolation of the upper surface heights from sea level data observed (usually) two and one-half hours earlier. Thus caution is indicated where surface conditions have changed rapidly subsequent to the surface observation and prior to the time of the upper surface map. An effort should be made to modify the earlier surface data as necessary before the extrapolation is made. Further, although the multi-variate diagrams are computed using virtual temperature, this transformation was not made in this analysis. There were two reasons for this. It is considered that this refinement is unwarranted considering the nature of the method and also that the lapse rate values suggested in this paper are based on observed temperatures.

The following separations were made and frequency tables developed therefrom. Mean effective lapse rates from sea level to 500 mb were used. Wind separation was made into four quadrants centered on the intercardinal points. Sea level pressure was divided into ten millibar increments, and

latitude into ten degree bands. The lapse rate figures, which had been read to within one one-hundredth of a degree centigrade per 100 meters, were grouped into ten one-hundredth intervals, centered on the even tenths value. The seasons are the even quarters of the calendar year.

In Appendix I are presented the frequency tables resulting from separation by latitude, season, and lapse rate. In Appendix II are found the results of the successive separation according to season, latitude, wind direction, and lapse rate. Appendix III shows the results of successive separation according to season, latitude, sea level pressure, and lapse rate. Finally, in Appendix IV, the frequency tables of complete successive separation according to season, latitude, wind direction, surface pressure, and lapse rate are given.

From the data contained in Appendix IV, Table 1 was compiled. This table is derived from the frequency tables and represents the "best" value of mean effective lapse rate to be used for various conditions as defined by the other parameters.

As a further aid in the selection of an appropriate mean effective lapse rate, monthly mean data for each of the several ocean weather stations was computed and the results are presented in Table 2.

By making a random selection of soundings from the file of Upper Air Bulletins, a test sample of 50 soundings was collected. The appropriate value of the mean effective lapse rate was selected from Table 1, the height computed by the multi-variate diagram, and the height thus obtained was compared with the observed height. The results of this test are presented in Table 3. In addition, heights were obtained using appropriate mean monthly lapse rate values from Table 2. The results of this technique are also noted in Table 3.

III. DISCUSSION OF RESULTS AND SUGGESTIONS FOR FURTHER INVESTIGATION

The comparative accuracy achieved by using lapse rate values from Tables 1 and 2 indicates little preference between the two. On the basis of the 50 sounding sample (3.6% of recorded observations), the difference in average error is considered insignificant. It is encouraging to note that the net mean error was minor in each case and did not show a constant trend of error. The determination of extrapolated heights to within 200 feet of the actual enables the analyst to be confident that the analysis includes all significant features of the height pattern. The normal number of ship reports available in the Pacific and Atlantic Ocean areas, in northern latitudes, should provide adequate coverage for complete analysis of the upper pressure surface maps.

Since the number of reporting ocean weather stations does not provide conclusive evidence for suggested lapse rate values for an entire latitude belt, these values must be used with caution in locations far removed from the stations available for this study. When the data presented herein is based on a reporting location well away from large land masses, particularly those to windward, the suggested values may be significantly smaller than those actually present over locations immediately to leeward of continents, even though in the same latitude belt. In high latitudes, the existence of extensive ice cover must be considered, with the suggested values of lapse rate being adjusted upward to compensate for the increased instability as the cold air moves out over the open water.

SUGGESTED MEAN EFFECTIVE LAPSE RATE VALUES

	Lat.	30-39 N.				40-49 N.				50-59 N.				62 N.			
	W.D. mb	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW
	104x										.3						
W	103x	.5	.5	.6	.5	.5	.3	.4	.3			.5		.6			
I	102x	.5	.5	.5	.5	.5	.4	.4	.3		.4	.5	.5	.6	.6	.6	
N	101x	.5	.6	.6	.6	.5	.4	.3	.5	.4	.4	.6	.7		.4	.6	.7
T	100x			.6	.6	.5	.5	.5	.5	.4	.4	.5	.7	.8	.4	.6	.7
E	99x					.6	.5	.5	.6	.4	.5	.6	.6	.8		.7	.8
R	98x					.6		.5	.5			.7	.7		.5	.8	.6
	97x												.6		.6	.7	.7
	96x											.7				.9	
	104x							.1									
S	103x	.5	.5				.4	.2	.1				.5		.5		
P	102x	.4	.5	.5	.5	.3	.4	.3	.3	.3	.4	.5	.5	.6			
R	101x	.4	.6	.5	.4	.5	.5	.4	.5	.5	.5	.5	.5	.6	.5	.7	
I	100x	.7		.6		.5		.5	.4	.5	.4	.5	.6	.4	.6		.7
N	99x					.6		.6	.6	.5	.4	.5	.6				
G	98x					.6			.6	.5	.4	.4	.5		.8		
	97x																
	96x																
	104x																
S	103x	.5	.5					.3	.3								
U	102x	.4	.5	.5	.5	.3	.4	.3	.3	.3	.3	.4	.4	.5		.3	.3
M	101x	.5	.5	.5	.5	.3	.4	.3	.4	.4	.3	.3	.4	.6	.4	.5	.5
M	100x			.5		.3	.4	.4	.4	.3	.3	.3	.4	.4	.5	.4	.5
E	99x						.4	.6			.3	.4	.4	.5	.4		
R	98x																
	97x										.5						
	96x																
	104x																
A	103x	.4										.6					
U	102x	.5			.5						.5	.5	.5	.4		.5	.6
T	101x	.5		.5							.4	.6	.5	.5		.4	.7
U	100x									.5	.5	.6	.7	.6	.6	.8	.6
M	99x									.6		.8	.7	.6	.7	.7	.6
N	98x										.5	.8	.5	.6	.6	.7	
	97x													.7		.7	
	96x										.7	.5				.6	

TABLE 1

[illegible]

[illegible]

[illegible]

MONTHLY MEAN DATA FOR SELECTED WEATHER STATIONS
(Compiled from soundings used in this investigation)

Location		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
62N-33W	(1)	19	19	12	9	4	16	18	17	10	24	28	24
	(2)	.69	.68	.54	.65	.56	.48	.37	.50	.43	.62	.58	.67
	(3)	.12	.09	.09	.11	.10	.08	.08	.10	.11	.09	.12	.08
52N-33W	(1)	14	17	12	17	15	14	21	21	6	26	28	24
	(2)	.54	.57	.39	.50	.48	.48	.31	.37	.39	.49	.56	.66
	(3)	.15	.14	.10	.10	.07	.10	.09	.08	.11	.11	.10	.10
56N-51W	(1)	19	19	8	16	8	10	15	7	14			
	(2)	.62	.73	.51	.61	.49	.36	.36	.36	.36			
	(3)	.16	.12	.12	.09	.12	.07	.08	.06	.09			
45N-45W	(1)	13	17	13	14	15	19	19	20				
	(2)	.48	.51	.44	.46	.40	.32	.34	.33				
	(3)	.12	.10	.07	.09	.11	.12	.08	.09				
49N-148W	(1)	20	14	13	19	21	26	24	26	26			
	(2)	.38	.43	.52	.58	.39	.31	.29	.34	.50			
	(3)	.11	.14	.10	.08	.10	.15	.08	.07	.13			
35N-40W	(1)			7	14	16	17	21	17	12			
	(2)			.57	.52	.54	.52	.52	.50	.53			
	(3)			.03	.06	.04	.04	.05	.05	.05			
34N-52W	(1)	14	17	12	13	17	16	23	19	1			
	(2)	.53	.56	.53	.53	.54	.50	.53	.52	.53			
	(3)	.06	.06	.04	.06	.05	.03	.04	.04	-			
30N-140W	(1)	18	19	16	18	14	26	26	28	21	21	29	23
	(2)	.43	.54	.57	.49	.45	.39	.37	.46	.47	.49	.43	.55
	(3)	.06	.06	.06	.06	.04	.05	.04	.04	.03	.05	.05	.06

Number of soundings on Line (1)
Average value, 500 mb mean effective lapse rate on Line (2)
Mean deviation from average value on Line (3)

TABLE 2

TEST DATA RESULTS

(Total soundings 1398)
(Test sample 50)

	Using Values from Table 1.	Using Values from Table 2.
Average error	175 ft.	155 ft.
Net mean error	+8 ft.	-15 ft.
Extreme error	640 ft.	410 ft.

TABLE 3

In this study, as in many others, it is regretted that the number of soundings available for analysis could not have been increased tenfold or more. The absence of sea level wind data precluded the use of many reports. It is considered that the fourteen hundred reports used were barely adequate to permit the formulation of Tables 1 and 2. Extreme values of the various basic parameters do not appear with sufficient frequency to insure accuracy of suggested lapse rate values in these cases.

Since the separations according to sea level pressure and/or wind direction were not completely definitive, certain other available data should be considered in future work. The curvature of surface isobars is believed to offer distinct possibilities. It is an easily determined variable and is closely related to the stability of the over-lying air mass. With access to suitable map files or with the publication of the Historical Weather Map Series for the period covered by this investigation, this parameter could be determined for each observation and the data entered on the existing cards. Separations could then be made accordingly with new frequency tables prepared therefrom.

Riehl [6], has published techniques applied in an analysis of lapse rate values for the 700-300 mb layer. The assumption that a mean lapse rate will also be the mean effective lapse rate between the two pressure surfaces, which is reasonably well satisfied for the 700-300 mb layer, is not satisfactory for the sea level-700 mb, or sea level-500 mb layers. The presence of frontal and subsidence inversions invalidates this assumption. Thus a knowledge of the temperature field at sea level and at the upper pressure surface does not necessarily yield an accurate mean effective lapse rate

for the layer. Further, a classification system according to location of the sounding in relation to troughs and ridges does not serve effectively in these lower layers. The sea level isobar configurations are usually more complex than the contour patterns aloft and would therefore require a much more complicated classification. It is believed that the suggested classification according to isobar curvature will achieve the desired separation. Riehl's method of dividing the lapse rate values according to temperatures of the 700 mb surface is sound for the upper layers, but does not apply in our problem. This is because the sea level air temperatures are controlled to a very great degree by the surface sea water temperature, and are not intimately related to the mean temperature of the air mass above. Hence, they exhibit primarily a latitudinal and seasonal gradient and are not suitable indicators of stability. Thus no segregation of lapse rate values has been attempted based on sea level air temperatures.

A source of possible error, present in this study, would be removed by obtaining and using microfilm copies of station data sheets, rather than the Upper Air Bulletin or Historical Weather Map Series. In each of these publications all errors of transmission and inaccurate punching of data cards add to the vagaries of statistical analysis. It is concluded that a number of the singular values of lapse rate obtained were due to erroneous primary data.

As has been noted above, a tenfold increase in the number of reports analyzed would most certainly have resulted in increased definitiveness.

With such a number of cases however, an effort should be made to utilize punch-card techniques and mechanical sorting.

Since the use of monthly-mean lapse rate values shows promise, and since they are readily obtainable, it is recommended that daily values of the mean effective lapse rate over each reporting ocean station be computed and recorded. Table 2 could then be revised as additional data was compiled and a noticeable increase in accuracy of extrapolation should ensue.

BIBLIOGRAPHY

1. Berry, F. A., Jr., et al. Handbook of Meteorology. New York, McGraw-Hill, 1945. p. 117.

2. Haltiner, G. J., and Eaton, M. A. Constant Pressure and Differential Analysis with Practical Applications. Annapolis, U. S. Naval Postgraduate School, 1948. Appendix II.

3. Haltiner, G. J. Multi-variate Diagrams: (1) Height of 700 mb surface from sea level pressure, temperature and average lapse rate. (2) Height of 500 mb surface from sea level pressure, temperature, and average lapse rate. Monterey, U. S. Naval Postgraduate School, 1949.

4. Namias, J. Construction of 10,000-foot Pressure Charts Over Ocean Areas. Bull. Amer. Met. Soc., 25:175 ff. May 1944.

5. Namias, J. Extended Forecasting by Mean Circulation Methods. Washington, U.S.W.B., 1947, pp 24-25.

6. Riehl, H. A Study of High-tropospheric Lapse Rates with Application to the Construction of 300 Millibar Charts. J. Amer. Met. Soc., 6:420-425, December 1949.

7. United States Weather Bureau. Daily Upper Air Bulletin. Washington and New Orleans. October 1948 through September 1949.

APPENDIX I.

FREQUENCY TABLES OF OBSERVATIONS IN GROUPS DEFINED BY LATITUDE AND 500 MB MEAN EFFECTIVE LAPSE RATE

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter Months										
62 N.				4	6	11	14	10	4	
50-59 N.	1	1	8	18	15	21	14	8	10	1
40-49		8	19	21	28	15	9		1	
30-39			2	18	49	42	9	2		1
Spring Months										
62 N.			3	6	12	7	5	5		
50-59 N.		4	9	15	27	15	8	3		
40-49 N.	10	15	23	18	20	20	8			
30-39 N.			7	38	78	22	6			
Summer Months										
62 N.		3	7	16	10	7	2			
50-59 N.	3	9	31	29	6	3	3			
40-49	3	20	33	36	12	5	5	1		
30-39		2	2	48	88	30	1			
Autumn Months										
62 N.			3	3	14	17	26	12		
50-59 N.		1	4	12	22	13	18	7	1	
40-49 N.				--- no reports ---						
30-39 N.			1	22	35	12	4			

APPENDIX II.

FREQUENCY TABLE OF OBSERVATIONS IN GROUPS DEFINED BY SURFACE WIND DIRECTION AND 500 MB MEAN EFFECTIVE LAPSE RATE, AFTER SEGREGATION INTO TEN DEGREE LATITUDE BANDS

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 62 N.										
NE					1	2		2		
SE		1		2	2	1	2			
SW				2	2	6	9	7	4	
NW						2	3	1		
Calm					1					
Spring 62 N.										
NE			3	3	5	3	2			
SE				2	3	2	1	2		
SW				1	2	1	1	2		
NW					2	1	1	1		
Summer 62 N.										
NE			1	4	4	4				
SE				6	1	1				
SW		3	4	4	3	1				
NW			2	2	2	1	2			
Autumn 62 N.										
NE			1	2	3	5	5			
SE					1	1	3	1		
SW				1	3	3	4	6		
NW					1	5	1	1		
No direction rep'd			1	1	6	5	11	4		

LAPSE RATE VS. WIND DIRECTION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 50-59 N.										
NE				5	1	1		1		
SE	1	1	2	4	2	3	2	1		
SW			5	9	8	11	4	2	1	1
NW			1		3	6	8	5	7	
Calm					1				1	
Spring 50-59 N.										
NE			3	2	9	4	2			
SE			3	6	4	3				
SW		1	3	4	7	4	1	2		
NW		3		3	7	4	5	1		
Summer 50-59 N.										
NE		1	4	4						
SE	2	4	11	6	1					
SW	1	4	11	9	5	2	2			
NW			4	11		2				
Autumn 50-59 N.										
NE				2	4	3				
SE				3	3	1	1			
SW			2	3	4	4	6	1		
NW			1	2	5	2	8	3	1	
No direction rept'd		1	1	2	6	3	5	1		

LAPSE RATE VS. WIND DIRECTION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 40-49 N.										
NE				2	4	2				
SE		2	4	8	7					
SW		2	8	5	7	4	4			
NW		4	7	6	10	9	5		1	
Spring 40-49 N.										
NE	1	2	4	2	8	3				
SE			3	3	2	2				
SW		6	12	2	6	5	7	3		
NW	3	4	10	6	5	7	5			
Calm			1			1				
Summer 40-49 N.										
NE		4	6	4	3		1			
SE		1	3	11	2	2				
SW	2	8	15	13	5	1	2			
NW	1	7	7	8	2	2	3			
Calm			1							

Autumn 40-49 N.

--- no reports ---

LAPSE RATE VS. WIND DIRECTION (CONCLUDED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 30-39 N.										
NE			2	7	21	7		1		
SE				4	11	8	1			
SW				2	13	17	2			
NW				4	4	9	5	2		1
Calm					1	1				
Spring 30-39 N.										
NE			7	22	10	5	2			
SE				4	18	10				
SW				7	35	4	3			
NW				5	13	3	1			
Calm					2					
Summer 30-39 N.										
NE		2	1	41	35	6				
SE					17	4				
SW			1		21	12				
NW				7	13	6	1			
Calm					1	3				
Autumn 30-39 N.										
NE				6	9		1			
SE										
SW					1					
NW					1					
No direction rep't			1	16	24	12	3			

APPENDIX III.

FREQUENCY TABLES OF OBSERVATIONS IN GROUPS DEFINED BY SURFACE PRESSURE AND 500 MB. MEAN-EFFECTIVE LAPSE RATE, AFTER SEGREGATION INTO TEN DEGREE LATITUDE BANDS

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 62 N.										
1030-1039 mb					1	1				
1020-1029					1	2	1			
1010-1019				2		1	1	1		
1000-1009			1	1	2	1	3	2		
990-999				1		1	2	4		
980-989					2	2	2	2	1	
970-979						3	5	1	1	
960-969									2	
Spring 62 N.										
1020-1029 mb				1	1					
1010-1019			1	4	7	3	4	3		
1000-1009			2	1	1	3	1	1		
990-999					2					
980-989					1	1		1		
Summer 62 N.										
1020-1029 mb		2	4		1					
1010-1019		1	2	8	6	5	1			
1000-1009			1	6	2	1	1			
990-999				2	1	1				
Autumn 62 N.										
1020-1029 mb					2	2				
1010-1019			1	1	2	1	5			
1000-1009			2	1	5	5	6	3		
990-999				1	2	5	8	5		
980-989					3	4	1	3		
870-979						1	3	1		
960-969							1	1		

LAPSE RATE VS. SURFACE PRESSURE (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 50-59 N.										
1040-1049 mb			1							
1030-1039					1					
1020-1029			3	3	5	3	2			1
1010-1019	1		3	8	2	6	2	2	7	
1000-1009		1	1	4	4	5	4	1	2	
990-999				3	3	6	2	3		1
980-989							3	2		
970-979						1				
960-969							1			
Spring 50-59 N.										
1030-1039 mb				1	2		1			
1020-1029		2	2	4	3	3	2	1		
1010-1019		1	1	2	12	5	2			
1000-1009		1	4	3	5	2	3	2		
990-999			2	2	2	4				
980-989				3	1	1				
970-979					1					
Summer 50-59 N.										
1020-1029 mb		2	5	4	2		1			
1010-1019	2	4	9	14	1	3				
1000-1009	1	2	15	6						
990-999		1	3	4	2	1	1			
980-989										
970-979					1					
Autumn 50-59 N.										
1030-1039 mb						1				
1020-1029			1	1	2		1			
1010-1019		1	1	1	4	1	5	1		
1000-1009			2	3	9	5	8	4	1	
990-999				2	3	5	1	1		
980-989				3	2	1	1	1		
970-979					1		1			
960-969				1	1		1			

LAPSE RATE VS. SURFACE PRESSURE (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 40-49 N.										
1030-1039 mb		3	6	2	4	1				
1020-1029		3	7	5	6	3				
1010-1019		2	2	9	9	2	5			
1000-1009			3	4	5	5	3		1	
990-999			1		3	3				
980-989				1		1	1			
970-979					1					
Spring 40-49 N.										
1040-1049 mb	2									
1030-1039	5	5	1	1	1	1				
1020-1029		5	15	6	5	1				
1010-1019		6	4	8	6	11	2			
1000-1009	2	1	3	3	7	4	3			
990-999					1	2	2			
980-989						1	1			
Summer 40-49 N.										
1030-1039 mb	1	1	1	1						
1020-1029	1	11	11	11	5					
1010-1019	1	8	16	18	6	1	3	1		
1000-1009		1	3	6	1	3	2			
990-999				1		1				
Autumn 40-49 N.										

--- no reports ---

LAPSE RATE VS. SURFACE PRESSURE (CONCLUDED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 30-39 N.										
1030-1039 mb				2	8	4	1			
1020-1029			2	15	28	12	3			1
1010-1019				1	12	24	4	2		
1000-1009					1	2	1			
Spring 30-39 N.										
1030-1039 mb					5	1				
1020-1029			6	25	53	14	1			
1010-1019			1	14	20	6	3			
1000-1009						1	2			
Summer 30-39 N.										
1030-1039 mb					2	1				
1020-1029		2	2	40	56	22				
1010-1019				8	28	8	1			
1000-1009					1					
Autumn 30-39 N.										
1030-1039 mb				1	1					
1020-1029			1	18	26	9	2			
1010-1019				2	8	2	1			
1000-1009						1	1			

APPENDIX IV.

FREQUENCY TABLES OF OBSERVATIONS IN GROUPS DEFINED BY SUCCESSIVE SEPARATION ACCORDING TO SEASON, LATITUDE, WIND DIRECTION, AND PRESSURE

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 30-39 N.										
NE Wind										
1030-1039					7	1				
1020-1029			2	8	11	5	1			
1010-1019					2	1				
SE Wind										
1030-1039					2					
1020-1029				4	9	3				
1010-1019					1	4	1			
SW Wind										
1030-1039						1				
1020-1029				1	3	2				
1010-1019				1	9	13	1			
1000-1009						2	1			
NW Wind										
1030-1039				2	1		1			
1020-1029				2	4	1	2			1
1010-1019						6	2	2		
1000-1009						1				
Calm										
1020-1029					1	1				

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 40-49 N.										
NE Wind										
1030-1039				1	1					
1020-1029					1					
1010-1019				1	1					
1000-1009					1					
990-999						1				
980-989						1				
SE Wind										
1030-1039		1	2	2						
1020-1029				2	2					
1010-1019		1		3	2					
1000-1009				2	2					
990-999			1		1					
SW Wind										
1030-1039			1		1					
1020-1029		1	4	2	2					
1010-1019		1	2		1		1			
1000-1009			1	2	2	2	2			
990-999					2	1				
980-989				1			1			
NW Wind										
1030-1039		2	2		2	1				
1020-1029		2	3	1	2	2				
1010-1019				5	5	2	4			
1000-1009			2			3	1	1		
990-999						1				
980-989										
970-979					1					

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Winter 50-59 N.										
NE Wind										
1010-1019				2	1			1		
1000-1009				1						
990-999				2		1				
SE Wind										
1040-1049			1							
1030-1039										
1020-1029			1	1		1				
1010-1019	1			3						
1000-1009		1	1	1	1	2				
990-999					1	1		1		
SW Wind										
1030-1039					1					
1020-1029				3	2	3		1		
1010-1019			3	3		5		1	1	
1000-1009				2	3	2				
990-999				1	2	1	1	1	1	
980-989							1			
970-979										
960-969							1			
NW Wind										
1020-1029			1		2				1	
1010-1019					1	1	2	1	4	
1000-1009						1	4	1	2	
990-999						4		1		
980-989							2	2		
970-979						1				
Calm										
1020-1029					1					
1010-1019									1	

SUCCESSIVE SEPARATION (CONTINUED)

Winter 62 N.

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
NE Wind										
1030-1039					1	1				
1020-1029						1				
1010-1019										
1000-1009								1		
990-999								1		
SE Wind										
1020-1029					1		1			
1010-1019				1						
1000-1009		1		1						
990-999										
980-989					1					
970-979						1	1			
SW Wind										
1020-1029						1				
1010-1019				1		1		1		
1000-1009					2		2	1		
990-999					1	1	2	2		
980-989						1	2	3		
970-979						2	3	2		
960-969									2	
NW Wind										
1010-1019							1			
1000-1009						1	1			
990-999								1		
980-989						1				
970-979							1			
Calm										
980-989					1					

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Spring 30-39 N.										
NE Wind										
1030-1039					2					
1020-1029			6	17	7	4				
1010-1019			1	5	1	1	1			
1000-1009							1			
SE Wind										
1030-1039					3	1				
1020-1029				4	14	5				
1010-1019					1	4				
SW Wind										
1020-1029				1	24	2				
1010-1019				6	11	1	2			
1000-1009						1	1			
NW Wind										
1020-1029				1	8	3	1			
1010-1019				5	4					
Calm										
1020-1029					1					
1010-1019					1					

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Spring 40-49 N.										
NE Wind										
1020-1029		2	3	2						
1010-1019		1	1		4					
1000-1009					5					
990-999						1				
980-989						1				
SE Wind										
1030-1039				1						
1020-1029			2	3	2					
1010-1019			1			2				
SW Wind										
1040-1049	2									
1030-1039	3	4			1	1				
1020-1029		1	3		1					
1010-1019		2	2	5		4	1			
1000-1009		2	1	1	2	2	1			
990-999					1		1			
NW Wind										
1030-1039	2	1								
1020-1029		2	7	1	2	1				
1010-1019		1	1	3	2	5	1			
1000-1009	1		1	3	1	1	2			
990-999							1			
980-989							1			
Calm										
1030-1039			1							
.....										
990-999							1			

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Spring 50-59 N.										
NE Wind										
1020-1029			1							
1010-1019			1		4	1	1			
1000-1009				1	2	1	1			
990-999				1	2	1				
980-989				1	1	1				
SE Wind										
1030-1039					1					
1020-1029				2						
1010-1019				1	2	2				
1000-1009			2	2						
990-999			1			1				
980-989				1						
SW Wind										
1020-1029				3	1	2	1	1		
1010-1019					4	1				
1000-1009		1	2		2			1		
990-999				1		1				
980-989				1						
NW Wind										
1030-1039				1	1	1				
1020-1029			2		2	1	1			
1010-1019		1		1	2	1	1			
1000-1009					1	2	1	1		
990-999					1	1				
980-989										
979-979					1					

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Spring 62 N.										
NE Wind										
1020-1029						1				
1010-1019			1	3	2	3	2	1		
1000-1009			2	1	1					
SE Wind										
1020-1029										
1010-1019				2	3	2		1		
1000-1009						2				
990-999										
980-989								1		
SW Wind										
1020-1029				1						
1010-1019							1	1		
1000-1009						1				
990-999					2					
NW Wind										
1010-1019					1					
1000-1009							1	1		
990-999										
980-989					1	1				

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Summer 30-39 N.										
NE Wind										
1030-1039					1	1				
1020-1029		2	1	37	25	5				
1010-1019				4	9					
SE Wind										
1030-1039					1					
1020-1029					10	3				
1010-1019					6	1				
SW Wind										
1020-1029			1		12	7				
1010-1019					8	5				
1000-1009					1					
NW Wind										
1020-1029				3	9	4				
1010-1019				4	4	2	1			
Calm										
1020-1029						3				
1010-1019					1					

[illegible]

[illegible]

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Summer 40-49 N.										
NE Wind										
1020-1029		1	2	1	2					
1010-1019		3	3	2	1		1			
1000-1009		1		1						
SE Wind										
1020-1029			1	2	2					
1010-1019		1	1	8						
1000-1009			1			2				
990-999				1						
SW Wind										
1030-1039		1	1							
1020-1029	1	4	5	4	1					
1010-1019	1	3	8	5	3			1		
1000-1009			1	4	1		1			
990-999						1				
NW Wind										
1030-1039	1			1						
1020-1029		6	2	4						
1010-1019		1	4	3	2	2	1			
1000-1009			1	1	1		1			
Calm										
1020-1029			1							

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Summer 50-59 N.										
NE Wind										
1020-1029		1		1						
1010-1019				1						
1000-1009			4	2						
SE Wind										
1020-1029			2							
1010-1019	1	2	4	4						
1000-1009	1	1	6							
990-999		1	1							
980-989										
970-979					1					
SW Wind										
1020-1029		1	2	2	2		1			
1010-1019	1	2	4	3	1	1				
1000-1009		1	4	1						
990-999			1	3	2	1	1			
NW Wind										
1020-1029			1	1						
1010-1019			1	6		2				
1000-1009			1	3						
990-999			1	1						

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Summer 62 N.										
NE Wind										
1020-1029					1					
1010-1019				1	1	3				
1000-1009			1	3	1					
990-999					1	1				
SE Wind										
1010-1019				4						
1000-1009					1	1				
990-999				2						
SW Wind										
1020-1029		2	2							
1010-1019		1	2	2	3	6				
1000-1009				2						
NW Wind										
1020-1029			2							
1010-1019				1	2	1	1			
1000-1009				1			1			

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Autumn 30-39 N.										
NE Wind										
1030-1039				1						
1020-1029				5	7		1			
1010-1019					2					
SE Wind										
		None reported								
SW Wind										
1010-1019					1					
NW Wind										
1020-1029					1					
No Wind Direction Reported										
1030-1039					1					
1020-1029			1	14	19	9	1			
1010-1019				2	4	2	1			
1000-1009						1	1			

SUCCESSIVE SEPARATION (CONTINUED)

Autumn (1948) 40-49 N.

--- No Reports ---

[illegible]

[illegible]

--- [illegible] ---

[illegible]

SUCCESSIVE SEPARATION (CONTINUED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Autumn 50-59 N.										
NE Wind										
1000-1009				1	3	1				
990-999				1	1	2				
SE Wind										
1020-1029				1	1					
1010-1019				1						
1000-1009					1	1				
990-999										
980-989				1	1					
970-979										
960-969							1			
SW Wind										
1030-1039						1				
1020-1029					1					
1010-1019			1		1		2	1		
1000-1009			1	2	1	3	2			
990-999								1		
980-989								1		
970-979										
960-969				1	1					
NW Wind										
1020-1029			1				1			
1010-1019					2		1			
1000-1009					2		5	3	1	
990-999						1	1			
980-989				2	1	1				
No Wind Direction Reported										
1010-1019		1			1	1	2			
1000-1009			1	1	2		1	1		
990-999				1	2	2				
980-989							1			
970-979					1		1			

SUCCESSIVE SEPARATION (CONCLUDED)

	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Autumn 62 N.										
NE Wind										
1010-1019				1	1	1	1			
1000-1009			1	1	1	2	2			
990-999					1	1	1			
980-989						1				
970-979							1			
SE Wind										
1000-1009					1		1			
990-999							2	1		
980-989						1				
SW Wind										
1020-1029					1					
1010-1019			1		1					
1000-1009								1		
990-999							3	2		
980-989					1	1		2		
970-979						1	1	1		
960-969						1				
NW Wind										
1020-1029					1	1				
1010-1019							1			
1000-1009						2				
990-999						2		1		
No Wind Direction Reported										
1020-1029						1				
1010-1019							3			
1000-1009			1		3	1	3	2		
990-999				1	1	2	2	1		
980-989					2	1	1	1		
970-979						1				
960-969						1				

APR 22 2ND T.L.(JBG) 765
3rd T.L. RENEWED
MAR 16 4.T.L. RENEWED
DEC 23 RENEWED
765
DE 17 57
INTERLIB
JA 21 58
7735.
JA 29 59
U.S Wea
~~7895~~

Thesis 13125
D52

Dibrell

Tropospheric lapse rates over selected ocean regions with applications to the construction of 700 and 500 millibar charts

and 500 millibar charts.

thesD52
Tropospheric lapse rates over selected o
3 2768 001 89368 8
DUDLEY KNOX LIBRARY